ADMINSTRATIVE INFORMATION

1. **Project Name:** Stress Assisted Corrosion in Boiler Tubes

2. **Lead Organization:** Institute of Paper Science and Technology
500 10th Street, NW
Atlanta
Georgia 30318

3. **Principal Investigators:** Preet M. Singh (IPST)
404-894 6641, fax: 404-894 478, preet.singh@ipst.edu

Steven J. Pawel (ORNL), (865) 574 5138, pwl@ornl.gov
J. R. Keiser (ORNL), (865) 574 4453, keiserjr@ornl.gov

4. **Project Partners:**

Industrial Partner	Points of Contact
Babcock & Wilcox	Mr. John Hainsworth
Hercules Inc.	Mr. Mel. Esmacher Mr. Norris Johnston
International Paper	Dr. Ray Vasudevan
Longview Inspections	Mr. Mike Cooper
MeadWestvaco	Dr. W. B. A. Sharp, and Mr. Steve Lukezich
Ondeo-Nalco	Mr. Paul Desch
Weyerhaeuser	Dr. Peter Gorog

5. **Date Project Initiated:** Project started in March 2002

6. **Expected Completion Date:** September 2005

PROJECT RATIONALE AND STRATEGY

7. Project Objectives:

Main objective of this research is to understand the role key environmental and stress conditions on initiation and propagation of SAC in carbon steel tubes. Secondary objective to achieve the above stated objective is to develop a laboratory test that simulates SAC in industrial boilers, and the control of key conditions of the test to establish the parameters that have the greatest effects on SAC initiation and propagation.

8. Technical Barrier Being Addressed

More than half of the power and recovery boilers that have been inspected reveal SAC damage, which portends significant energy and economic impacts. SAC is indicated by crack-like fissures that initiate and propagate on the waterside of boiler tubes, typically near external attachment welds. Propagation of SAC (with or without concomitant external corrosion) can lead to de-rating of boilers and tube failures, possibly resulting in potential smelt-water explosions and extended downtime for maintenance or repairs.

9. **Project Pathway:**

The work was divided into five tasks.

1. In the first task, a test system is to simulate SAC in the laboratory. This was important to be able to control the key parameters to see their effect on initiation and propagation of SAC
2. The second task is to characterize the materials parameters associated with SAC that must be duplicated in the laboratory tests.
3. The third task is to identify key factors in the influence of residual and operating stresses. This will involve the measurement and modeling of stresses associated with different types of attachment welds and studies of the yield strength of waterside scales.
4. The fourth task will evaluate environmental effects (chemicals, pH, oxygen content on the initiation and propagation of SAC, both with field measurements and in laboratory tests, and through a critical analysis of a large amount of field inspection data that will be supplied by industrial partners in the project.
5. Last but not the least task is to communicate the results of the research to US industry.

10. Critical Technical Metrics:

Technical success of this project will depend upon how closely we can simulate boiler water conditions in the laboratory. One measure is to be able to develop a magnetite film on the carbon steel surface, which should be similar to the one on boiler tubes under normal boiler conditions. Taking this as a baseline, effect of chemical and electrochemical conditions on the morphology and properties of magnetite film will be evaluated. Critical stress/strain for crack initiation and microstructural effects are other two important factors. Success of project also depends on accurate measurements of stress in field so that FEM model can be correctly validated.

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:**

Main objective of this research is the development of a laboratory test that simulates SAC in industrial boilers.

- A special autoclave with recirculation loop was designed and commissioned at IPST in FY03 to simulate the waterside conditions in industrial boilers. Sensors for monitoring an controlling the water chemistry have been tested.
- Tests were done in FY 04 to develop magnetite film on the carbon steel surface and was successful.
- Morphology and other properties were measured for magnetite films developed under different conditions.

Comparison study was conducted at ORNL to evaluate capability and sensitivity of radiography and two types of ultrasonic inspection techniques to detect SAC in tubes removed from a recovery boiler.

- In one technique, ultrasonic waves were introduced longitudinally on the cold side surface of the tube and reflection analysis (at the wave launch location or a remote location) was performed to identify potential circumferentially oriented flaws.
- In a second technique, ultrasonic waves were introduced circumferentially from the process side of the tubes to locate longitudinally oriented flaws near attachment welds.
- These tubes were further sectioned and cleaned. A number of tested tubes in this study showed significant (10-20 mils) SAC cracks which could not be detected by these NDT techniques.

A large number of failed boiler tubes were received at ORNL and IPST from the industrial partners for failure analysis

- A number of tubes were sectioned and mounted to reveal SAC cracks and microstructural features associated with crack initiation.

12. **Planned Future Milestones:**

- In FY 05 on of the main tasks will be to identify a boiler to put strain gages on the boiler tubes and measure tube strains during shutdowns, startup and under normal boiler operations. The tubes with and without attachment welds will be identified for this study.
- A mathematical model is being developed at ORNL to estimate the corresponding stresses on the tube ID surface where waterside cracks form.
- In FY 05 we will continue tests in recirculation-loop autoclave at IPST to evaluate environmental effects (chemicals, pH, oxygen content on the initiation and propagation of SAC.
  - Results from the laboratory will be compared with boiler experiences through a critical analysis of field inspection data that will be supplied by industrial partners in the project.
- An important part of this project is to exchange of information with the U. S. companies for whom SAC is a significant issue.
  - Work from these studies will be presented to the industry through a colloquium next year as well as through presentations at various conferences including Corrosion-2005 at Houston, and TAPPI Engineering Conf. in 2005.

Task ID	Milestone	Planned Completion	Actual Completion	Comments
1.0	**Lab simulation of SAC**			
1.1	Establish autoclave operation	April 2003	Completed	Autoclave and heaters are working satisfactorily
1.2	Develop tensile test rig	August 2003	In-Progress	
1.3	Simulate SAC in lab tests	Sept. 2004	In-Progress	
1.4	Oxide growth experiments	Sept 2004		
2.0	**Material characterization**			
2.1	Examine tubes with SAC	Sept. 2003	Completed	Various tubes were received and were examined at ORNL and IPST
2.2	Document inspection reports	Dec. 2003	In-progress	
2.3	Inspections to assess SAC rate	Sept. 2004		
3.0	**Evaluation of stress effects**			
3.1	Document failure reports	April 2003	In-progress	Some data was received and is being reviewed. Required information is

				missing in most cases
3.2	Deploy field strain gages	Dec. 2004	In-Progress	
3.3	Model internal stress/strains	Sept 2004	In Progress	
4.0	**Environmental effects**			
4.1	Assess key chemistry data	Mar. 2004	In - progress	
4.2	Deploy on-line monitoring	Oct. 2004		
4.3	Document effect of cleaning	Sept. 2004		
5.0	**Communication to US industry**			Presentations were made at TAPPI and NACE meetings and appropriate Committees attended by US industry reps.
5.1	Technical review meetings	Every six months	In-progress	Second meeting will be held in June 2003
5.2	Special topic workshops	Once a year		
5.3	Final report	Sept. 2005		

13. Project Changes:

We have not encountered any major technical barriers so-far in this project which will force us to deviate from our proposed path. However, we are aware that accelerating factors for lab tests may negatively influence key factors being analyzed for the development of SAC in the laboratory. Therefore we will try to take care of this so that the results of accelerated testing will be evaluated for metallographic similarities to boiler-SAC and a limited number of long term exposures (with accelerating factors reduced or eliminated) will also be completed for comparison with results of accelerated tests. In-spite of these issues, we do not anticipate any big deviations from our proposed tasks or budget for FY-05.

14. **Intended Market and Commercialization Plans/Progress:**

- Boiler tubes in various industries including petroleum, chemical, glass, pulp and paper, and metal industry have experienced stress assisted corrosion (SAC). In the pulp and paper industry, any water leak in the boiler can result in boiler explosion. Therefore, the intended market for the application of results from this project is very wide. Main goal of this project is to clarify the mechanism(s) of stress-assisted corrosion of boiler tubes for the purpose of determining key parameters in its mitigation and control.
- Main product of this research will be SAC mitigation strategies in terms of water chemistry control, identification and avoidance of susceptible metallurgical microstructures and better welding/design practices to minimize strains on tubes to avoid fracture of protective scale. It is anticipated that the results will yield increased operating efficiencies represented by

decreased downtime (greater intervals between inspection and maintenance cycles) with associated energy and cost savings.

- Commercialization of key results from this project will be accomplished through the R&D partners and industry contributors, who will use SAC mitigation information generated through laboratory simulation results as well as field measurements.

15. **Patents, publications, presentations:**

- Presentation at Boiler water treatment subcommittee for the Recovery Boiler Committee at the TAPPI Engineering meeting at San Diego in 9th September, 2002.
- Presentation at TEG-163X meeting held during NACE 2003 Conference at San Diego, in late March. Representatives from water treatment companies, inspection companies as well as boiler owner representatives attended this meeting.
- Presentation and poster at OIT-IMF annual review meeting at Albuquerque, NM
- Preet M. Singh, Jorge J. Perdomo, Jamshad Mahmood, Pablo Conde, *Stress Assisted Corrosion in Laboratory*, Paper #04518, Corrosion-04. New Orleans, March 2004.
- S. J. Pawel, A. W. Willoughby, H. F. Longmire, P. M. Singh, *An Experience with Detection and Assessment of SAC in a Recovery Boile,* Paper #04519, Corrosion-04. New Orleans, March 2004.